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PB-258 817

Flue Gas Desulfurization and Sulfuric Acid Production via Magnesia Scrubbing Capsule Report

Environmental Protection Agency, Cincinnati, Ohio

May 75

Environmental Protection Agency, Cincinnati, Ohio. Office of Technology Transfer.

295015

PB 258 817

EPA TECHNOLOGY TRANSFER

CAPSULE REPORT

FLUE GAS DESULFURIZATION AND SULFURIC ACID PRODUCTION VIA MAGNESIA SCRUBBING

PREPARED BY U.S. ENVIRONMENTAL PROTECTION AGENCY

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PB258817

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-625/ 2-75-007	2.
3. RECIPIENT'S ACCESSION NO.	
4. TITLE AND SUBTITLE Flue Gas Desulfurization and Sulfuric Acid Production via Magnesia Scrubbing	5. REPORT DATE Publication Date: May 1975
	6. PERFORMING ORGANIZATION CODE ----------
7. AUTHOR(S) ----------	8. PERFORMING ORGANIZATION REPORT ----------
9. PERFORMING ORGANIZATION NAME AND ADDRESS Same as box #12	10. PROGRAM ELEMENT NO. 1HD622
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U. S. Environmental Protection Agency Technology Transfer Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Technology Transfer
	14. SPONSORING AGENCY CODE EPA-ORD

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Air Pollution	Desulfurization Magnesia scrubbing	

PRICES SUBJECT TO CHANGE

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
1. Paper Copy from Technology Transfer Cincinnati, Ohio 1 2. Microfiche	Unclassified	30
	20. SECURITY CLASS (This page) Unclassified	22. PRICE $4.00

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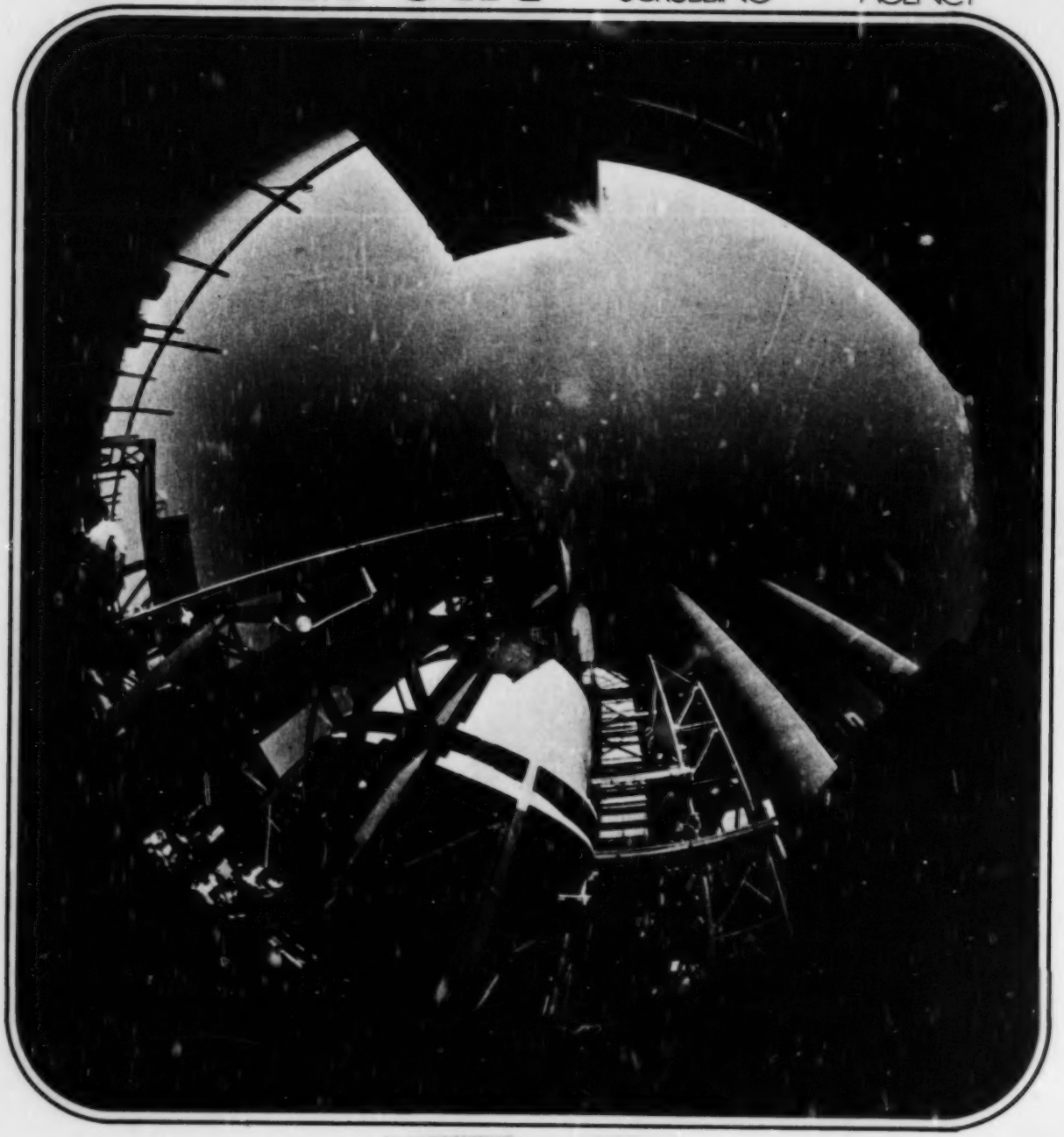

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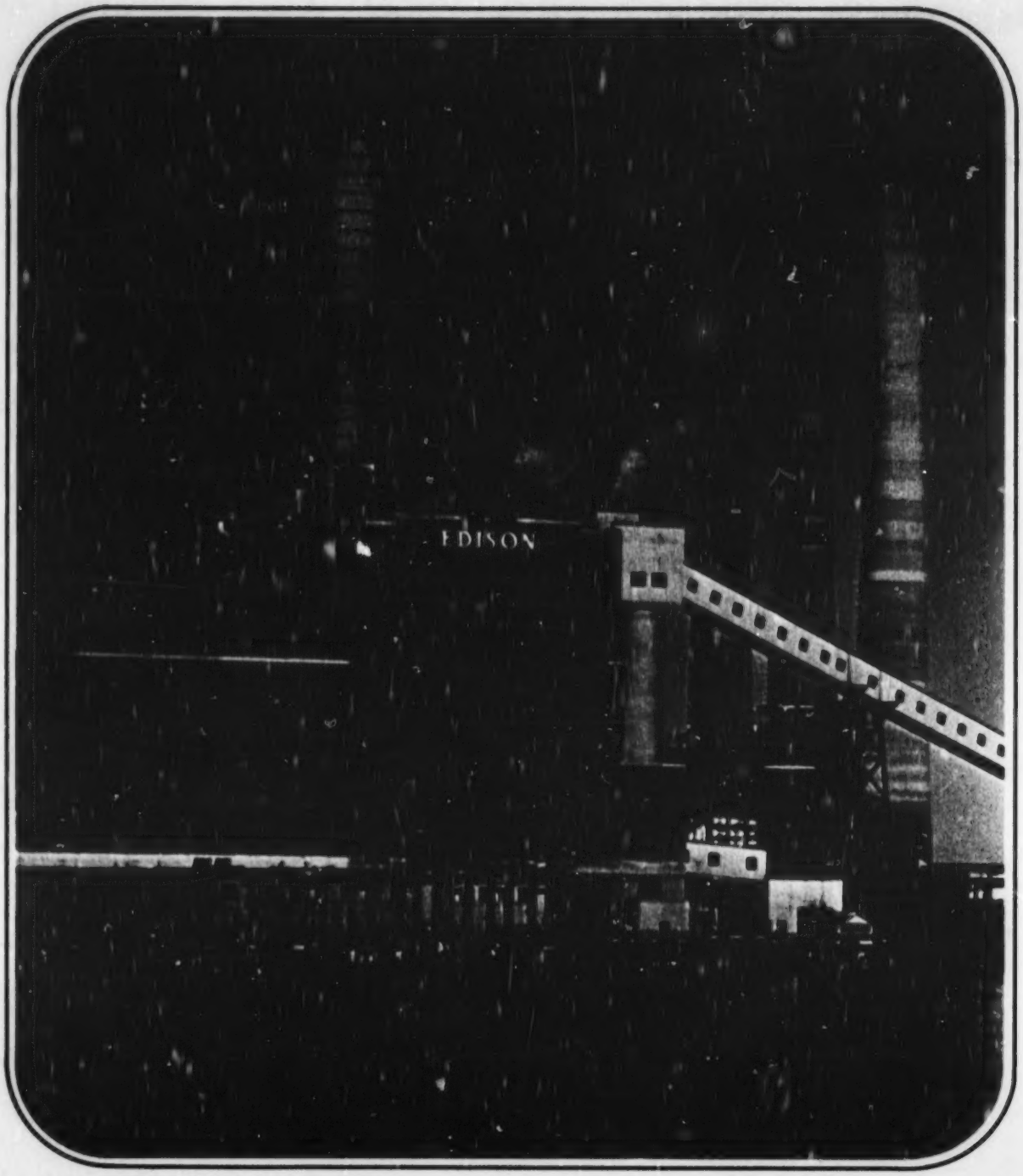


Boston Edison oil-fired power plant

1. THE SIGNIFICANCE

The 1970 amendments to the Clean Air Act provided increased impetus to programs directed to decreasing sulfur dioxide (SO_2) emissions from existing sources. These amendments also required the development of national emission standards for new sources.

It is estimated that approximately 20 million tons per year of sulfur must be removed from coal and fuel oil or from their combustion gases to meet SO_2 air quality standards. Approximately 55 percent of the SO_2 emissions in the United States result from the combustion of coal and oil at power-generating stations.

There are only three methods available to substantially reduce SO_2 emissions from these power generating stations: (1) switching to low sulfur fuels; (2) desulfurizing or converting the fuel prior to combustion; or (3) desulfurizing the gases produced by combustion. Because of the limited availability of low sulfur fuels and the relative infancy of coal desulfurization/conversion technology, flue gas desulfurization (FGD) processes are expected to make the most significant impact on abatement of SO_2 emissions until at least 1985.

FGD processes are generally divided into two categories: "throwaway" and "regenerable." Throwaway processes involve absorption of the flue gas SO_2 with the subsequent precipitation of a solid that is disposed of as a waste material. In regenerable processes, on the other hand, the SO_2 is absorbed and recovered in a manner such that its fixed sulfur value can be converted into usable and salable sulfur byproducts, such as sulfuric acid, elemental sulfur, or liquid SO_2. Commercial application of FGD technology by electric power plants has been limited in this country principally to the use of throwaway processes. These processes use aqueous slurries of lime or limestone as the SO_2 absorption media and produce a calcium sulfite/sulfate sludge for disposal. In some cases the disposal of this sludge has been a problem for utility plants operating in areas where sludge disposal costs are high and disposal area is limited.

About 40 million tons of sulfuric acid are manufactured per year in the United States. The major portion is obtained by burning mined elemental sulfur to SO_2, and processing the SO_2 to sulfuric acid. Regenerable FGD processes have the capability of substituting sulfur collected from flue gases for the mined sulfur. Power-generating stations, operating in areas where land is scarce and having the proper combination of technology, markets, and transportation, could find regenerable FGD processes to be the most economical solution for meeting SO_2 emission requirements.

One of the more promising regenerable flue gas desulfurization processes is based upon the reaction of magnesium oxide (magnesia) with SO_2, forming magnesium sulfite. The magnesium sulfite solids are separated by centrifugation, dried to remove moisture, and then calcined to regenerate magnesium oxide for recycle and SO_2 for conversion into sulfuric acid. Once properly conditioned, the SO_2 can be used by existing as well as new sulfuric acid plants.

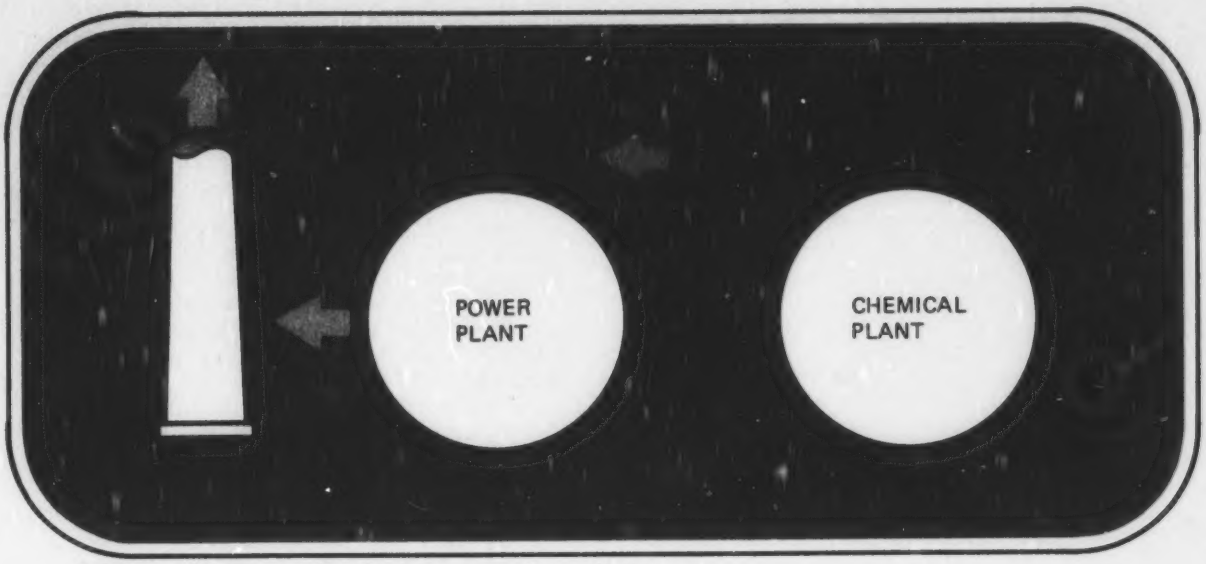
Although laboratory and pilot work had been done on the process by 1970, several major questions on full-scale application of the process remained.

(1) The ability to efficiently remove sulfur oxides from the flue gases.
(2) The ability to continually regenerate a reactive magnesium oxide.
(3) The quality of the product sulfuric acid.
(4) Mechanical and materials reliability.
(5) Projected construction and operating costs.
(6) Transport and storage properties of the magnesium sulfite and regenerated magnesium oxide.

In 1970, the U.S. Environmental Protection Agency and the Boston Edison Company agreed to provide the funds for the construction and 2-year operation of a large prototype sulfur dioxide recovery plant based upon magnesia slurry scrubbing. The Chemico-Basic magnesia process was chosen. The SO_2 absorption plant was installed at Boston Edison's Mystic Station in Everett, Massachusetts, and the regeneration facility at Essex Chemical's Rumford, Rhode Island, sulfuric acid plant. The process was scaled up from a small pilot plant handling 1,500 cubic feet per minute (cfm) of gas to a full-size unit designed for 450,000 cfm.

The prototype plant operated from April 1972 to June 1974 on a 155-megawatt (Mw) boiler at the Boston Edison facility. During this same time period the system's ability to regenerate and reuse magnesium oxide was demonstrated and over 5,000 tons of sulfuric acid were produced from magnesium sulfite at the Essex Chemical facility and sold in the commercial market. Mechanical and chemical problems that developed during the prototype operation at both Boston Edison and Essex Chemical were solved by either direct modification to the plants or by recommended solutions considered applicable to new magnesia scrubbing installations. The scrubbing system demonstrated a consistent ability to achieve SO_2 removal efficiences in excess of 90 percent using regenerated magnesium oxide.

2. PROCESS DESCRIPTION



FGD and H_2SO_4 production via magnesia scrubbing

The magnesia slurry process can be generally split into two major operating areas:

(1) SO_2 scrubbing, slurry dewatering, and magnesium sulfite drying, which were integrated into the Boston Edison plant operations.

(2) Magnesium oxide regeneration and sulfuric acid production, which were integrated into the Essex Chemical plant operations at Rumford, Rhode Island.

The dried magnesium sulfite was transported by truck to the Essex Chemical plant, and regenerated magnesium oxide was returned to Boston Edison.

Boston Edison SO_2 Recovery System

Figure 1 is a process flow sheet for the operations associated with the magnesia slurry SO_2 recovery system on Boston Edison's Mystic Station Unit No. 6 boiler.

Flue gas is ducted into the venturi scrubber, with an additional induced draft fan operating at the discharge of the existing fan. Since fuel oil was being burned at the Boston plant, there was no need for particulate matter removal.[1]

At the venturi scrubber, the flue gas is contacted concurrently with an aqueous recycled slurry containing magnesium oxide (MgO), magnesium sulfite ($MgSO_3$), and magnesium sulfate ($MgSO_4$). The absorption reaction takes place between sulfur dioxide and magnesium oxide, resulting in the formation of magnesium sulfite. Some of the SO_2 may also react with $MgSO_3$ in the presence of water to form magnesium bisulfite ($Mg(HSO_3)_2$), which then reacts immediately with the excess MgO present to yield additional $MgSO_3$. MgO, in slight excess (2.5 percent) of the amount necessary for reacting with all of the SO_2 present in the flue gas, is maintained in the slurry. A portion of the sulfur trioxide (SO_3) present in the flue gas is absorbed in the slurry and reacts to form $MgSO_4$. Additional amounts of $MgSO_4$ are also formed due to oxidation of a portion of the magnesium sulfite.

The aqueous slurry used as the scrubbing media contains the hydrated crystals of MgO, $MgSO_3$, and $MgSO_4$, as well as a solution that is saturated with each of these components. A continuous side-stream of this recycled slurry is diverted to a centrifuge, where partial dewatering produces a moist cake containing crystals of $MgSO_3 \cdot 3H_2O$, $MgSO_3 \cdot 6H_2O$, $MgSO_4 \cdot 7H_2O$ and unreacted MgO. The liquor removed from the crystals is returned to the main recirculating slurry stream. MgO, regenerated from the Essex Chemical plant, is combined with water and is then added to the recirculating slurry as make-up. The resulting

[1] For coal-fired applications, however, particulate matter removal would be required to avoid large-scale contamination of the magnesia slurry with fly ash.

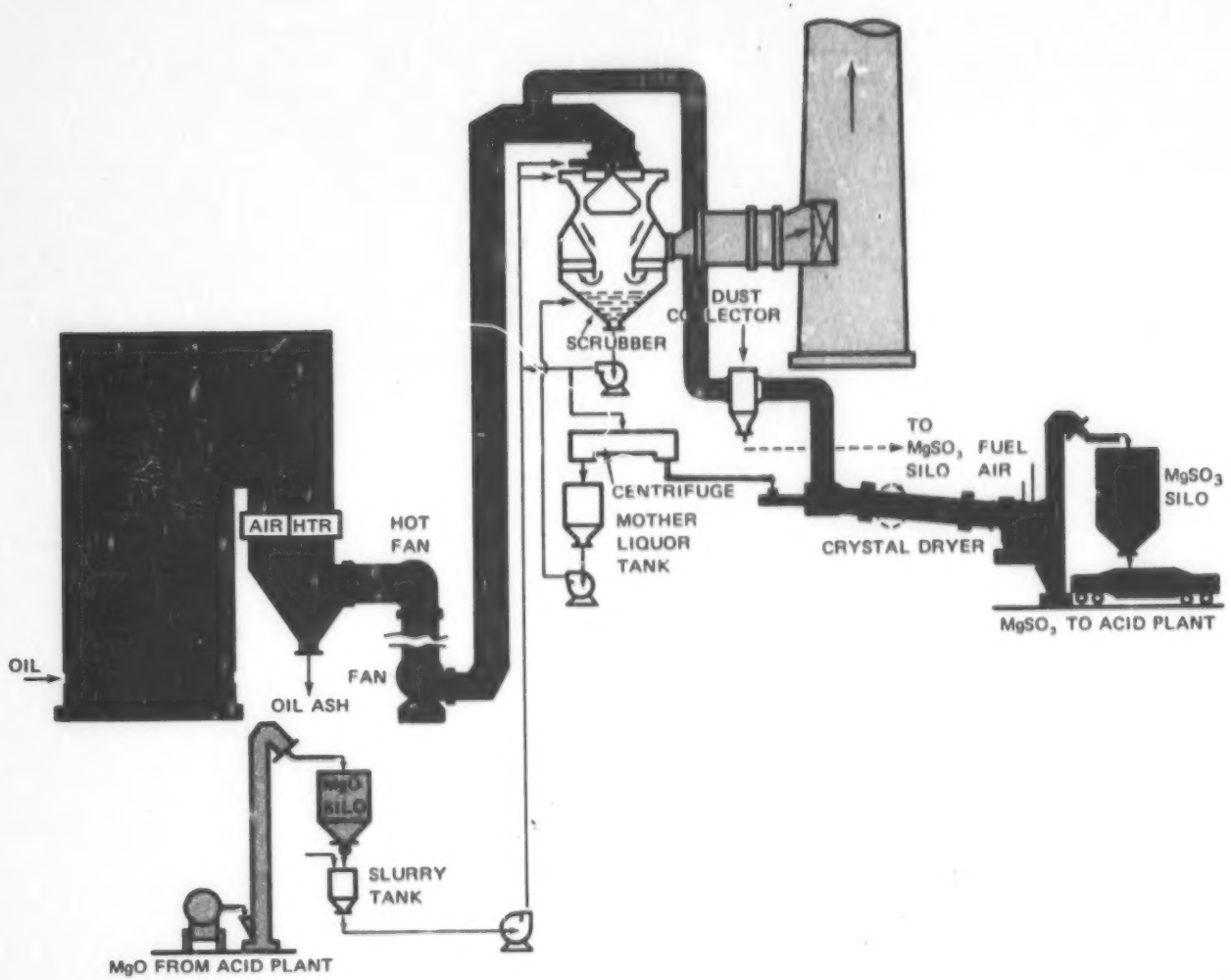


Figure 1. Process flow sheet—Boston Edison SO_2 recovery system

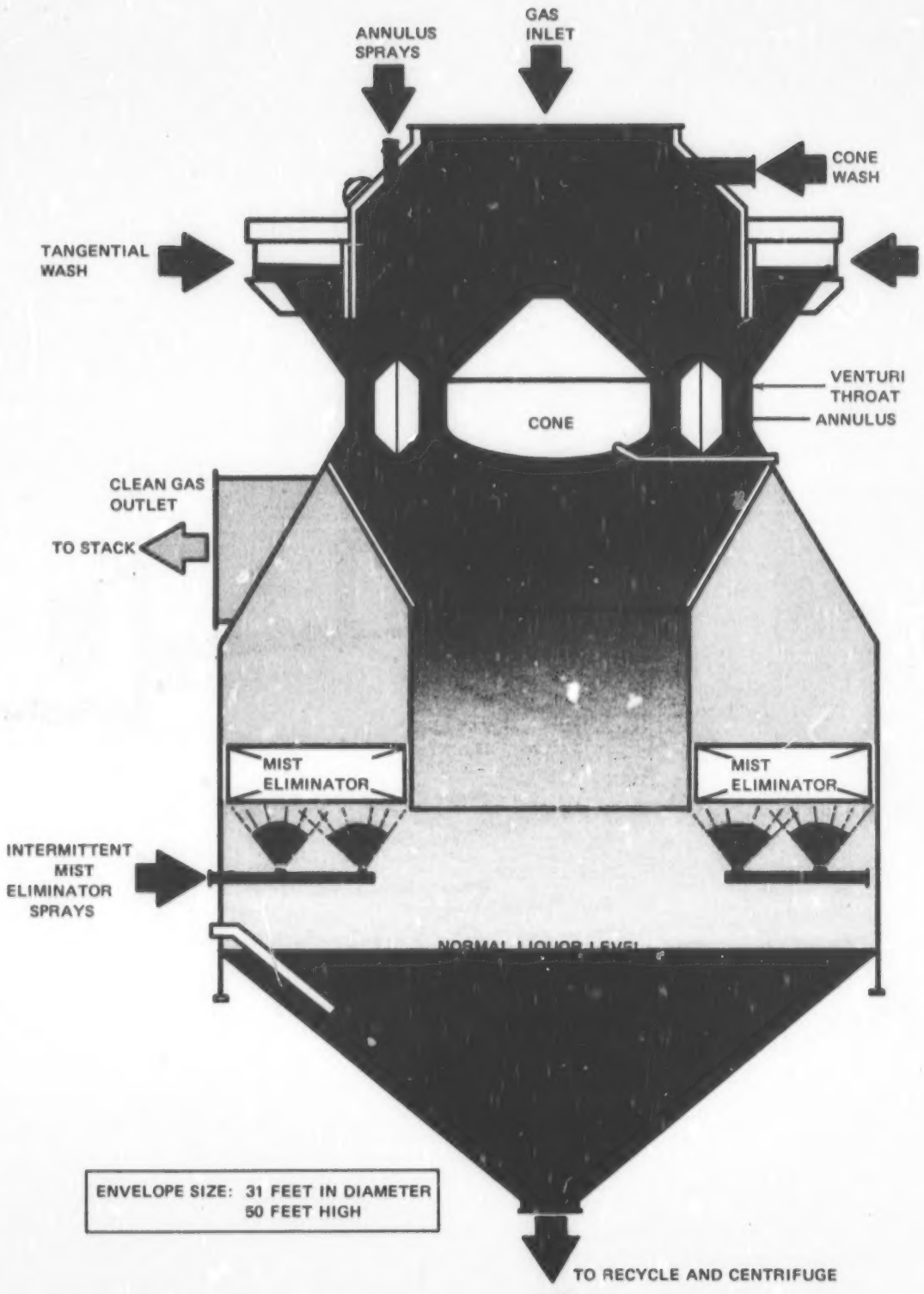
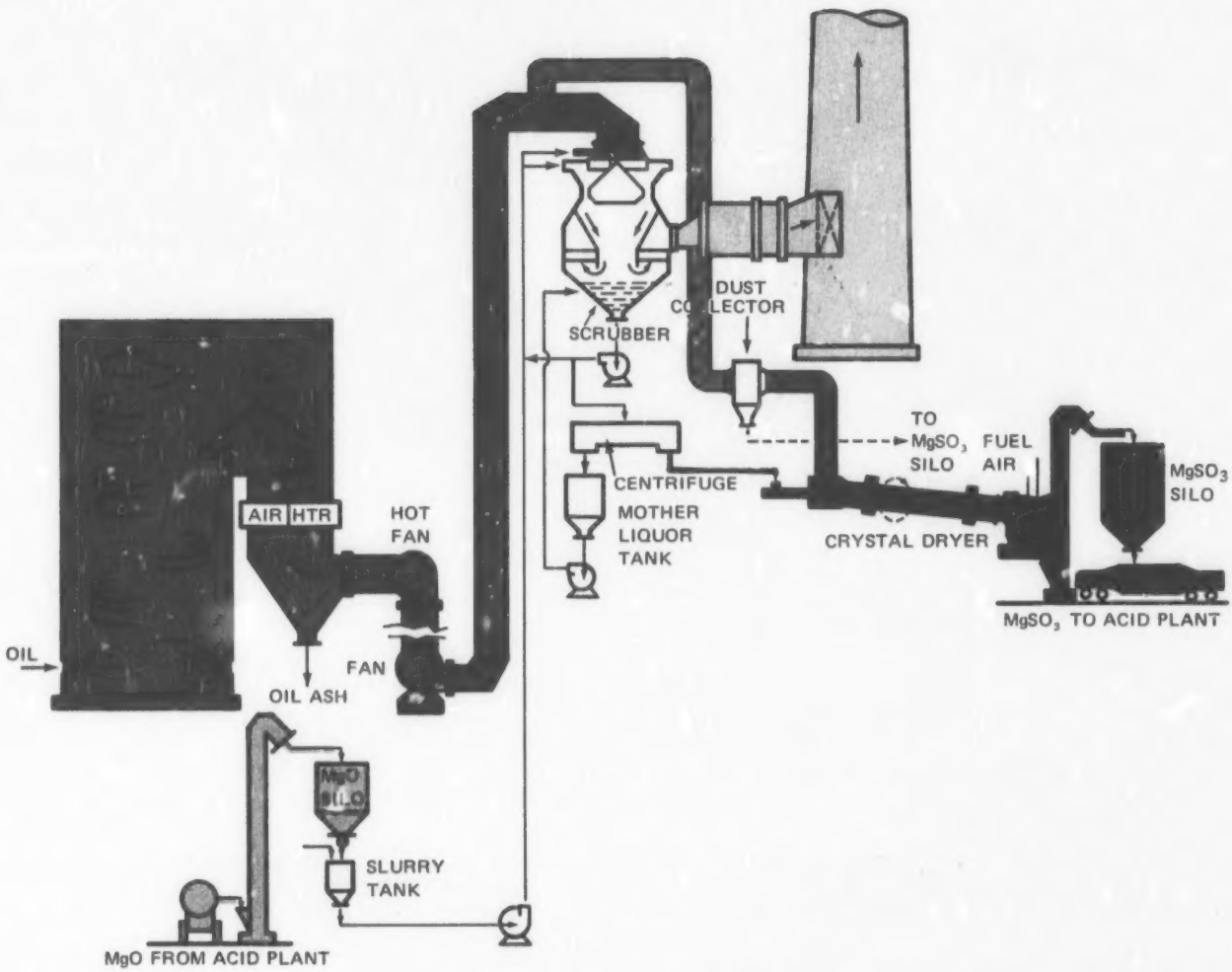


Figure 2. Cross-sectional view of venturi scrubber



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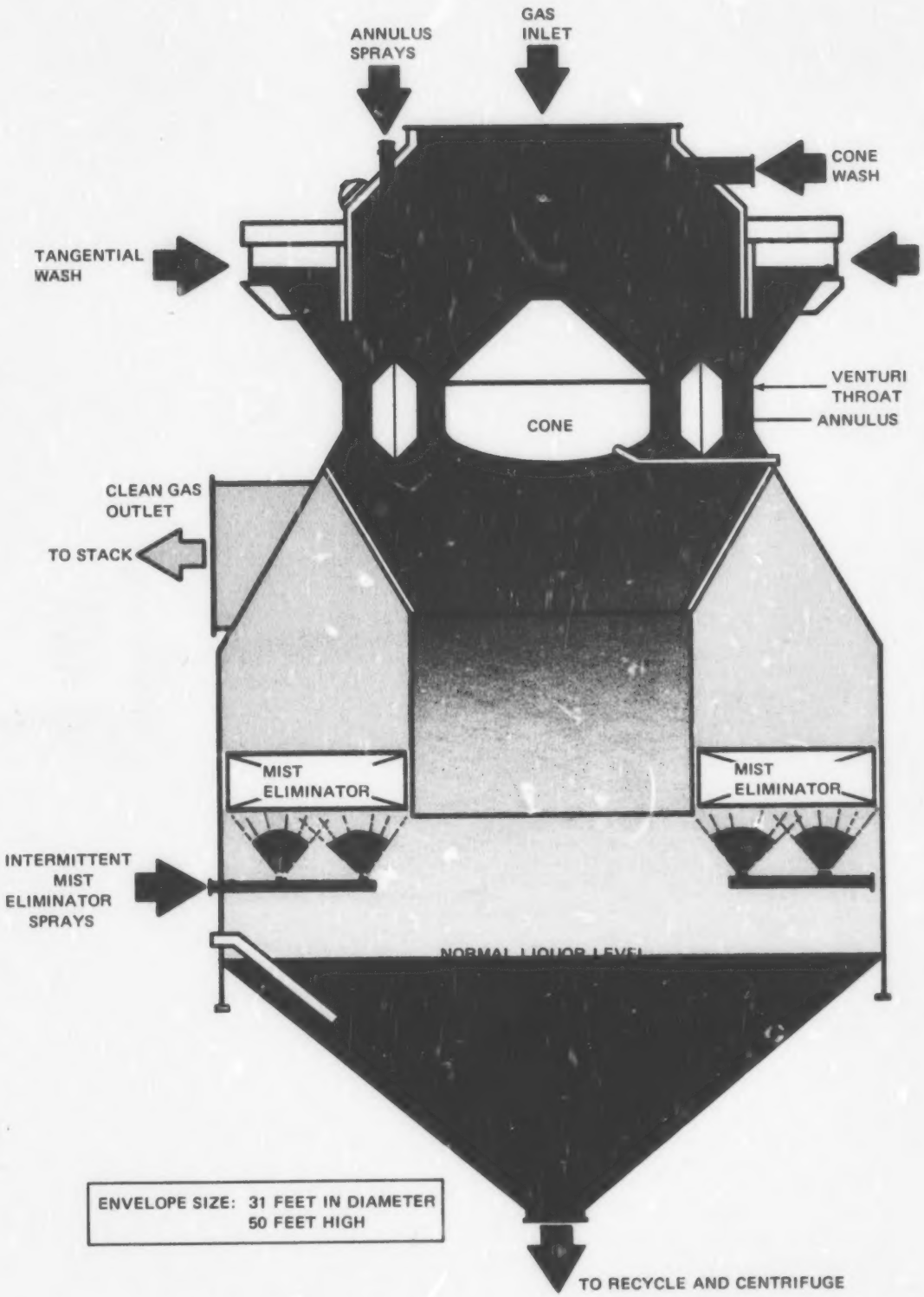

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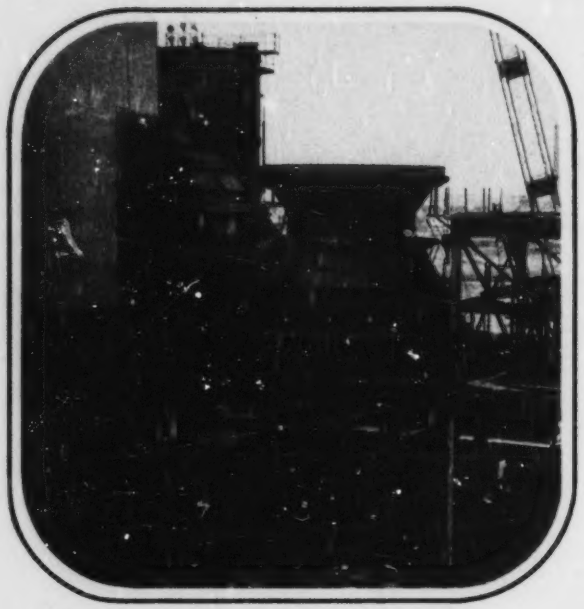


Magnesia scrubber during construction

combined slurry is recycled to the scrubber for continuous SO_2 recovery. The wet solids are conveyed to an oil-fired direct-contact dryer where free and bound moisture is removed. The dry magnesium sulfite is then stored for shipment to the sulfuric acid plant.

The scrubbing unit was installed to treat all of the flue gas from the Unit No. 6 boiler at Boston Edison's Mystic Station. Unit No. 6 burns 9,700 gallons per hour of No. 6 fuel oil at its current rated capacity of 155 Mw and was placed in commercial operation in May 1961.

Since the SO_2 scrubbing system was retrofitted into an existing boiler, an additional booster fan was installed to provide the required pressure.

The venturi scrubber must provide good contact of the gas with the liquid and not allow any solids buildup. The venturi must also be designed to operate at a minimum pressure drop to keep the scrubber's energy consumption low. The Chemico-designed venturi scrubber used at Boston Edison is shown in figure 2.

The slurry is introduced into the venturi through three points: (1) a nozzle that irrigates the cone within the venturi throat; (2) annulus sprays located above the torus surrounding the cone; and (3) tangential nozzles located in the top shelf of the scrubber. The slurry flow is downward across the venturi throat creating a curtain of liquor through which the flue gas passes. The flue gas rapidly accelerates to a high velocity at the throat where impact with the slurry causes atomization into fine droplets. SO_2 is mixed with the dispersed slurry and reacts with the magnesium salts. The slurry is continuously recycled from the conical bottom of the venturi scrubber, which also serves as a storage reservoir for the system. The flue gas and entrained slurry leaving the throat enter the separator portions of the scrubber through a central downcomer. The slurry droplets fall to the sump of the scrubber while the flue gas passes upward through mist eliminators for further removal of entrained materials. The cleaned flue gas exits the scrubber and enters the stack for discharge to the atmosphere.

The removal of some particulate matter, principally carbonaceous material in the 1-5-μm size range, also occurs in the scrubber. Unlike fly ash from coal combustion, the presence of carbon particles from oil combustion does not affect the reuse of MgO, since carbon is consumed in the regeneration step as a reductant for magnesium sulfate. The slurry of $MgSO_3$, $MgSO_4$, and unreacted MgO is then recirculated to the scrubber. To maintain equilibrium conditions, a continuous bleed of the recirculated slurry removes, as $MgSO_3$ and $MgSO_4$, the same amount of sulfur that the slurry absorbs from the flue gas. This bleed stream is taken from the discharge of the slurry recycle pumps and is set at a level that maintains the desired solids concentration in the recirculated slurry. MgO must be added to the recirculating slurry to replace the magnesium salts which are removed by the bleed stream. This is done by adding MgO makeup slurry at a rate that maintains the recycle slurry in the desired pH range of from 6.8 to 7.5.

The wet solids from the centrifuge (at about 40 percent surface water) are transported by means of a screw conveyor to a countercurrent, direct oil-fired rotary dryer where eventually all surface moisture and most of the water of hydration are driven off.

Offgas exits the dryer at about 450° F and passes through a cyclone dust collector where entrained solids are removed and conveyed to the storage silo. The dryer offgas then passes through an induced draft fan and is ducted back to the scrubber, which captures and reuses particulate matter from the dryer.

The dryer product, which consists of anhydrous MgO (< 1%), $MgSO_3$, $MgSO_4$, and inerts, is transported by a bucket elevator and screw conveyor to an existing storage silo. Material from the silo is transferred by means of screw feeders to a belt-conveyor, where it is gravity fed into trucks for transport to the MgO regeneration plant at Rumford, Rhode Island.

Operational SO_2 recovery system

Essex chemical plant,
Rumford, Rhode Island

Essex Chemical—MgO Regeneration and Sulfuric Acid Production

The chemical plant operations convert the magnesium sulfite-magnesium sulfate mixture received from the power plant back into magnesium oxide for recycle to the Boston Edison plant. In addition, the SO_2 produced from the regeneration of MgO is cleaned, cooled, and dried to make it suitable for feed to the existing sulfuric acid plant.

Essex Chemical's single absorption contact sulfuric acid plant in Rumford, Rhode Island, was built in 1928 and upgraded in 1949. With a nominal capacity of 50 tons per day of 98 percent H_2SO_4, this plant by today's standards is relatively small. This capacity closely matches the proportional sulfur output from the power plant's Unit No. 6 boiler. The plant was originally designed to use elemental sulfur as a raw material. Subsequent modifications made under the EPA program adapted the plant to acid production from calciner gas and/or sulfur burning.

The process sequence for regeneration used at Essex Chemical is shown in figure 3. The heart of the process is the calcination step, in which the following major reactions occur:

$$MgSO_3 \rightarrow MgO + SO_2$$
$$2C + O_2 \rightarrow 2CO$$
$$MgSO_4 + CO \rightarrow MgO + SO_2 + CO_2$$

The calciner is fed a weighed mixture of the magnesium sulfite/sulfate solids received from the power plant. If the amount of carbon present in the dried solids received from the power plant is inadequate for the reduction of magnesium sulfate to magnesium oxide, the calcination reaction requires the addition of coke.

The dried solids-carbon mixture moves countercurrently to the combustion gases that are formed by the direct firing of fuel oil. Since combustion gases dilute the SO_2 produced by the regeneration reaction, the calciner firing rate is maintained at the minimum level required for proper calcining conditions. Temperatures at the middle of the calciner are kept at approximately 1250° F.

Prior to discharge at the calciner's fired end, the MgO product is cooled to 250° F by direct heat exchange with the oil burner's secondary combustion air. The magnesium oxide is then moved to a storage silo by a screw conveyor and bucket elevator. A vibrating hopper assists in the transfer of the MgO from the storage silo to the trucks used to return the MgO to the power plant.

The SO_2 cycle continues as the SO_2-rich gases are discharged from the calciner's feed end. These gases then pass through cyclone dust collectors, where an entrained fine particulate product is removed and returned to the calciner.

Before its use in the acid plant, this SO_2-rich gas stream must be cooled and cleaned of dust and acid mist. A weak acid venturi scrubber performs the necessary cooling and cleaning functions in two sections:

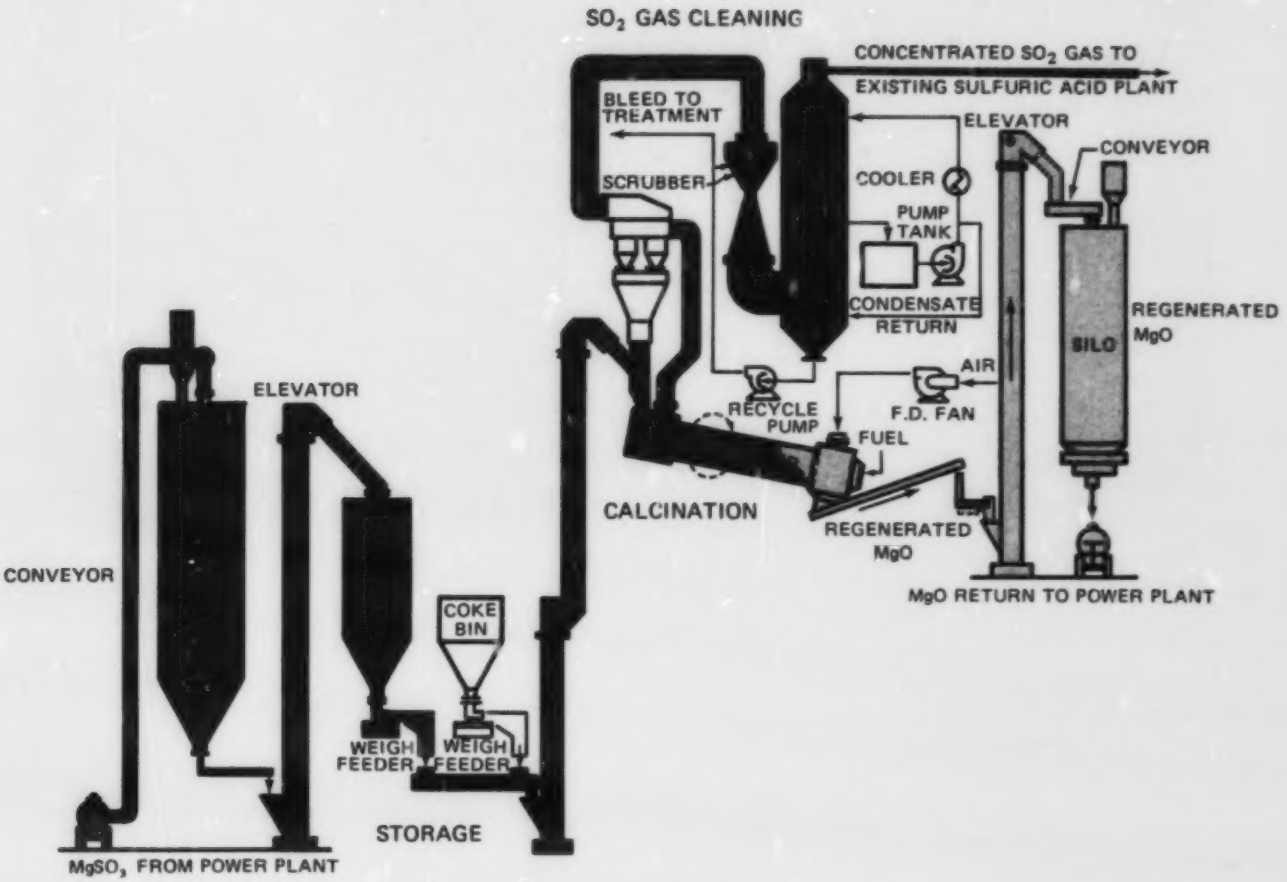
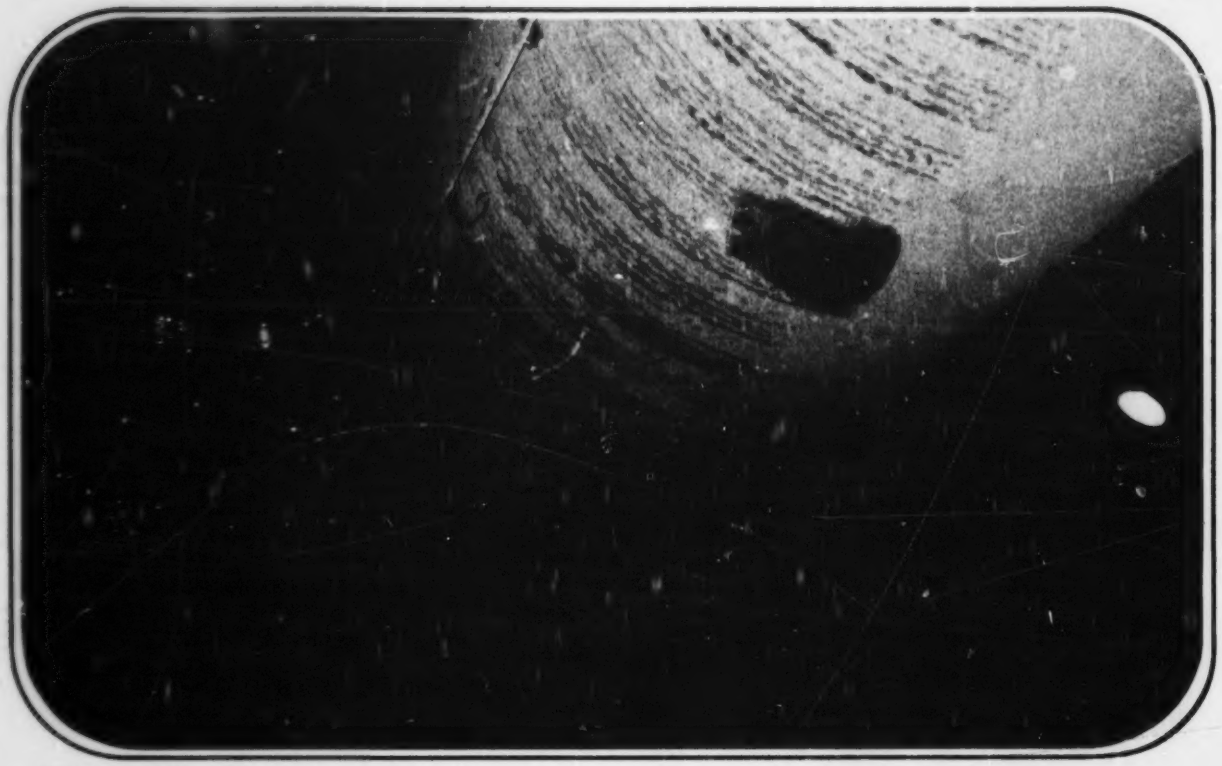


Figure 3. Process flow sheet—Essex Chemical MgO regeneration system



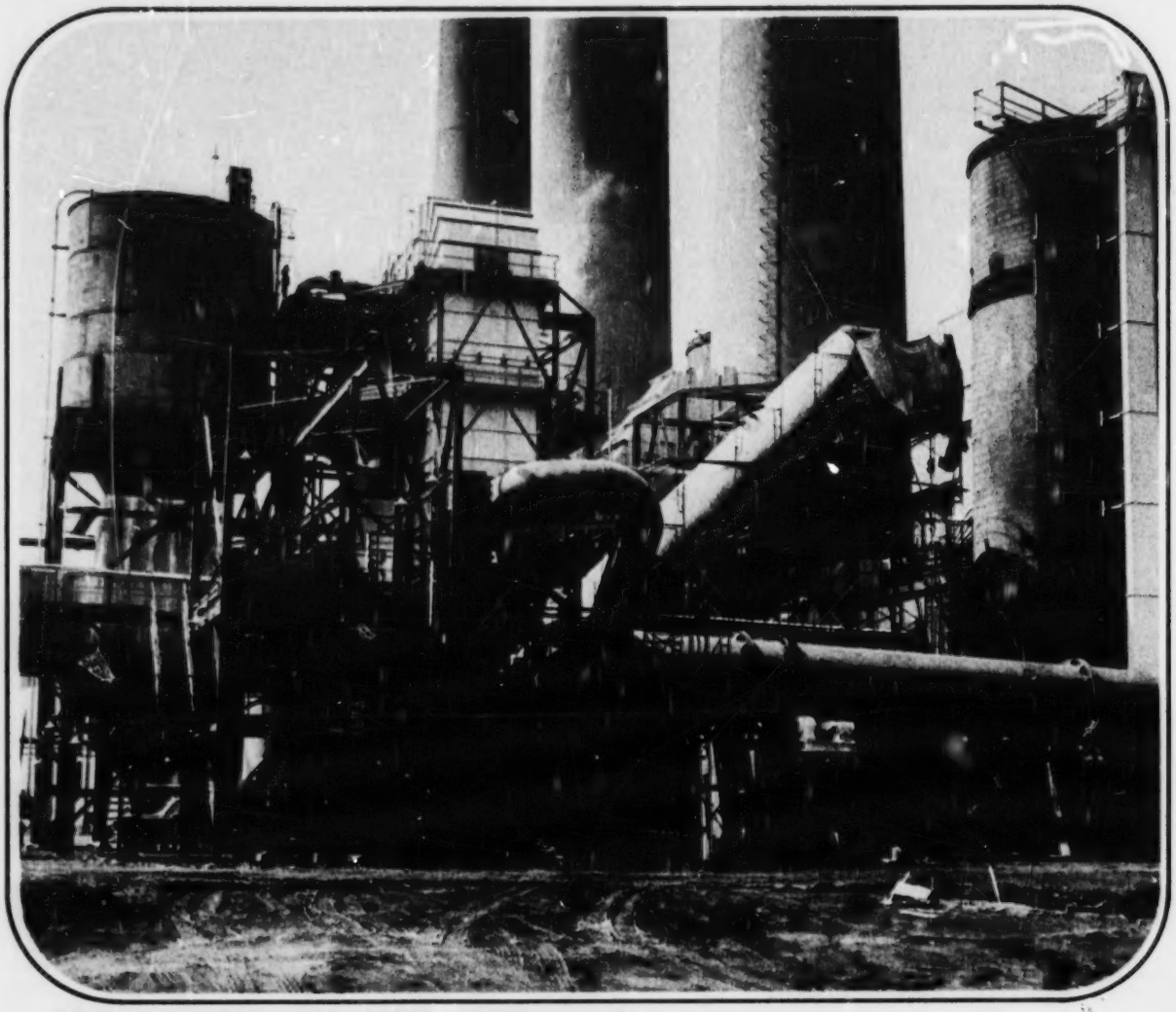
Calciner with mechanical rappers

(1) The venturi section, where the gases are cooled to the adiabatic saturation temperature and also scrubbed of particulate matter by a stream of recirculated weak acid scrubbing liquor.
(2) A packed tower, where the gases are further cooled by direct contact with a cool recirculated weak acid stream. This step is required since the gases leaving the venturi section are saturated with water vapor. By maintaining the exit temperature of the scrubber gas below 100° F, the introduction of more water than can be accepted by the sulfuric acid plant producing 98 percent acid is avoided. A purge stream is diverted from the recirculating scrubber liquor to an SO_2 stripping tower and then to a neutralizing step prior to discharge. This stream is necessary to maintain suspended solids, temperature, and pH of the recirculating scrubber liquor at specified levels.

The scrubbed gas stream is then transported through polyester pipe to the existing acid plant, where the gas is dried by contact with 93 percent sulfuric acid. After the gas stream leaves the drying tower, it is sent to an entrainment separator, which insures that no entrained acid will reach the main blower.

The dried gases are then drawn through the main blower and enter the cold heat exchanger. Here, the waste heat from the gas exiting the secondary converter is recovered by preheating the relatively cold calciner gas before it enters the existing converter heat exchanger. Downstream of the converter heat exchanger, acid production is the same as conventional acid production from the burning of elemental sulfur.

3. PERFORMANCE



Magnesia scrubbing system with dryer in foreground

A major objective of this project was to identify and resolve operating problems which were expected in the first large-scale application of this new process. The project did experience several problems that were not previously encountered. These problems were either solved by either direct modification to the two plants or solutions were recommended that were considered applicable to new magnesia scrubbing installations. The use of procedures developed as a result of this project should insure reliable startup and operation for future plants.

Table 1.
Test results

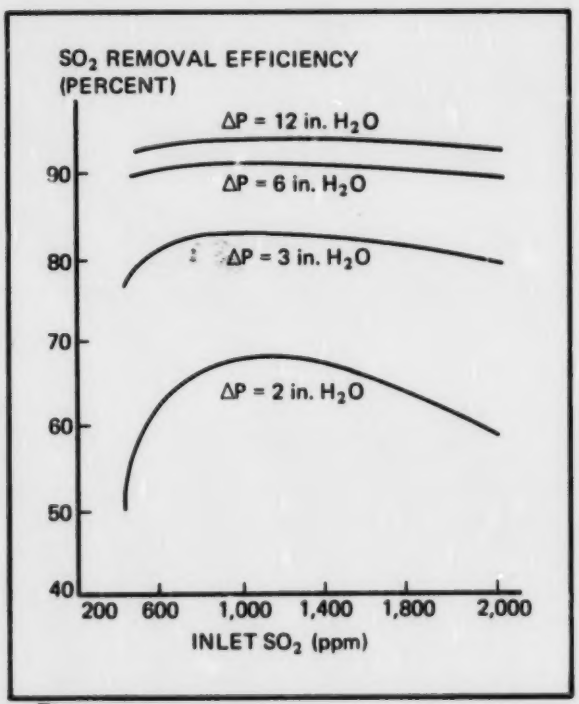


Figure 4.
Effect of ΔP and inlet SO_2 Concentration on SO_2 removal efficiency

Item	% of total stream				
	Solids	MgO	$MgSO_3$	$MgSO_4$	Water and inerts
Recycle slurry	20*	1.4	6.7	12.4	80
Centrifuge cake	63	1.4	57.8	4.1	37
Dryer product	80	2.6	65.0	11.8	20
Calciner feed	79	2.8	63.9	12.7	21
Calciner product	94.5	86.1		8.4	5.5

*Approximately 10% as suspended solids in the slurry.

Table 2.
Typical composition of major product streams

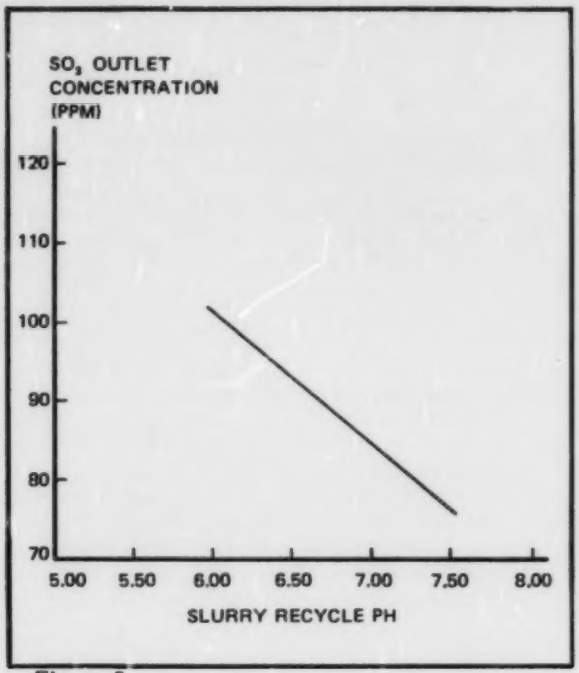


Figure 5.
Effect of slurry recycle pH on SO_2 outlet concentration

Boston Edison SO_2 Recovery System

The chemical and mechanical performance of the scrubbing system itself was excellent. None of the internal plugging problems which plagued the early operations of the lime and limestone processes were encountered. The plastic lining of the scrubber was in sound condition after 2 years of operation. Erosion and corrosion were experienced in the carbon steel recirculating slurry piping. The use of rubber-lined pumps, valves, and piping in certain areas of this system is now considered as the most practical solution to this problem. The SO_2 removal efficiency was excellent over a wide range of operation.

Table 1 lists the results of four controlled tests at varying flue gas rates and SO_2 inlet concentrations. These were contract performance tests and were conducted by a third party, York Research.

A correlation of SO_2 removal efficiency as a function of inlet SO_2 concentration and pressure drop across the scrubber was developed based on actual test data and is shown graphically in figure 4. In this same figure, the excellent operability range of the system is shown by the consistently high removal efficiency curves for pressure drops above 6 inches of water.

In addition, the scrubbing system faced frequent boiler outages during the last 6 months of the project. Repeatedly, the scrubbing system demonstrated its ability to maintain high SO_2 removal efficiencies while cycling with the boiler. The scrubber could also operate from a cold start of the boiler and could provide efficient scrubbing during the entire startup sequence.

The major control variables used to control the scrubbing operation were the recycle slurry pH and percent solids. The effect of pH on SO_2 concentration is shown in figure 5. The effect was controlled by adjusting the rate of MgO addition. Typical compositions of the recirculating slurry are shown in table 2, along with other key streams. The amount of solids in the slurry was controlled by adjusting the rate of bleed from the recycle slurry.

The majority of the operating problems experienced at the power plant operation were closely tied to the solids-handling system. Many of these problems were due to the nature of the magnesium sulfite crystals obtained from the scrubber. Although large, easily separated magnesium sulfite hexahydrate ($MgSO_3 \cdot 6H_2O$) crystals were expected, any sustained operation of the scrubber resulted in the production of many fine magnesium sulfite trihydrate ($MgSO_3 \cdot 3H_2O$) crystals.

This unexpected occurrence resulted in crystal properties different from those used in the design of the solids-handling system and the dryer, and was the primary process problem encountered in the project. Modifications eventually were required in all of the process areas handling magnesium sulfite crystals to allow for operation with large amounts of the trihydrate present.

The rotary dryer, used for removing free and bound water from the centrifuge slurry solids, was found to be at the center of these initial operating problems. Since this dryer was designed for operation with the relatively coarse hexahydrate crystals, the fine trihydrate crystals caused excessive dusting, buildup of solids, and loss of drying ability. The following modifications led to reliable drying:

(1) The dryer operation and internal configuration were modified to allow the dryer to act as a granulator for the fine crystals.
(2) A scalping screen and lump breakers were installed at the dryer discharge to handle large agglomerations of dried magnesium sulfite from the dryer.

(3) High dust losses from the dryer because of the fine crystal size were corrected by piping the dryer offgas to the venturi scrubber.
(4) Hammers were installed on the dryer shell to prevent the buildup of solids.
(5) The dryer conveyor was lengthened to allow wet centrifuge cake to be added at a point further into the dryer,
(6) The mixing of the dry material, removed from the cyclone dust collector operating on the dryer offgases, with the wet centrifuge solids created a mixture which would "set up" on the screw conveyor. A pneumatic conveyor system was installed to transport this material directly to the $MgSO_3$ silo.

As the first regenerated magnesium oxide arrived at the power plant for reuse, other problems in solids handling developed. The calcined magnesia returned from the acid plant contained a fraction of a larger-than-desirable particle size as well as some overburned MgO particles that would not react with water to form a reactive slaked slurry. A pulverizer was installed to grind this oversized MgO to that which was usable. This pulverizer was eventually transferred to the acid plant. In addition, magnesium oxide returning from the acid plant initially showed a lower reactivity than expected. This was corrected by heating the MgO slurry tank to 180° F to increase the slaking rate of the MgO.

The combined effects of corrosion and erosion were experienced in all pumps, valves, and piping that handled the scrubbing slurry. Because the prototype plant was designed for only a 2-year period of operation, cast iron and carbon steel were used in these areas and quickly failed. Rubber or plastic lining is now considered necessary in slurry-handling applications.

While centrifuge performance was generally satisfactory, improved internal washing techniques were required to reduce wear and improve reliability.

The availability of the SO_2 recovery system to the Boston Edison Unit No. 6 boiler ranged from a low of 13 percent to a high of 87 percent during the April 1972 and June 1974 operating period. Many of the lower-valued availabilities were caused by the problems discussed above. During the last 4-month period of the recovery system's operation, the monthly availabilities were 87 percent, 81 percent, 57 percent, and 80 percent. The lowest reported value was due to the lack of MgO for SO_2 removal, caused by problems in the sulfuric acid plant and an intentional emptying of the MgO silos during a controlled system test.

Essex Chemical – MgO Regeneration and Sulfuric Acid Production

After solving several initial operating problems, which are discussed in the following paragraphs, the chemical plant was consistently able to manufacture high quality 98 percent sulfuric acid, which was sold in the commercial market. Over 5,000 tons of H_2SO_4 were made from captured flue gas sulfur. During this same period, 3,000 tons of magnesium oxide were regenerated and shipped to the power plant for reuse.

The continued ability of the system to operate efficiently with regenerated magnesium oxide was a major variable investigated during the project. The occasional formation of a small amount of less reactive MgO was observed. This was generally accompanied by an increase in density of the magnesia. Data from this test program were correlated by regression analysis with operating conditions and the percentage of carbon in the feed to predict operating conditions which would result in a low-bulk-density magnesia. This correlation is shown in figure 6 and indicates that the formation of low-bulk-density (high-reactivity) magnesia is favored by low calciner temperature and an increased amount of carbon in the calciner feed.

Mechanical problems at the chemical plant were centered around the calciner operation. One such problem was air leakage into the calciner's firing hood. The calciner must operate very near neutral or at reducing conditions in order to allow for the reduction of magnesium sulfate to magnesia. A considerable amount of effort was expended in tightening up seals and reducing air leakage. The problem was finally solved by the installation of a friction seal.

Another problem occurred when oil was fired during the startup of the cold calciner. Hydrocarbon vapors not removed by the scrubbing equipment entered the sulfuric acid towers, which immediately caused the charring and blackening of the acid. This problem was solved by installing a fan and a short stack, which allowed the startup vapors to bypass the sulfuric acid plant. This system was used only when heating up the calciner and was never operated during periods of SO_2 generation.

MgO Losses

During the early period of operation, magnesium oxide losses were excessive due primarily to spills and required cleanouts caused, as previously described, by the solids-handling problems.

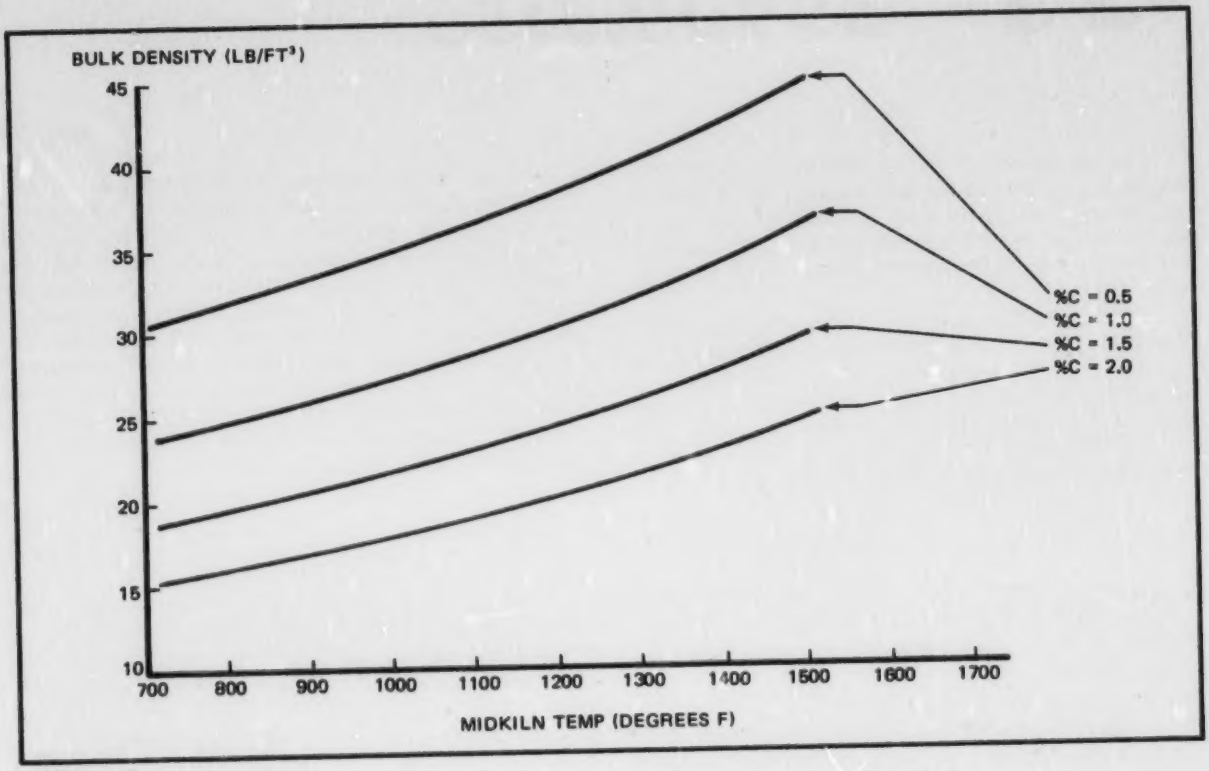


Figure 6.
Effect of midkiln temperature and calciner feed carbon on magnesia bulk-density

Boston Edison

In the final 4 months of operation, however, the bulk of these problems was solved, and a careful measurement was made of system losses. During these 4 months, 1,500,000 pounds of regenerated material were recycled to the power plant as scrubber slurry makeup. A 13-day test to identify each specific loss point was also conducted. The measurements showed a loss over the entire power plant operation of 0.37 ton per operating day, distributed as follows:

Loss to stack	0.13 ton per day
Scrubber overflow	0.14 ton per day
Miscellaneous accounted for losses	0.07 ton per day
Unaccounted for losses	0.03 ton per day
Total	0.37 ton per day

With an average MgO consumption of 10.61 tons per day during this period, this total loss amounted to 3.5 percent of MgO consumption at the power plant. The design loss at this same location was predicted to be 5 percent.

Essex Chemical

The greatest losses for this project occurred at the regeneration plant in Rumford, where 0.5 ton per day was scalped off the calciner product as large lumps before the pulverization process. Future system design will provide for the reclaiming of these losses. In addition, 1.5 tons per day were lost from the neutralizer overflow. In subsequent designs, this large loss can be recovered for recycle by separation of solids in the neutralizer overflow. Thus, almost all of the regeneration plant losses can be reclaimed by improved design at new regeneration plants.

4. ECONOMICS

The economics of flue gas desulfurization with magnesia and the subsequent production of sulfuric acid are complex issues and vary widely with the availability of nearby markets for sulfuric acid, as well as the price differential between high- and low-sulfur fuels.

In this report, the economics of a large-scale arrangement similar to that of Boston Edison and Essex Chemical are examined. The power plant ships dried magnesium sulfite to the chemical plant and receives regenerated dry magnesium oxide. A fee must be paid to the chemical plant for conversion. The savings, which the power plant realizes from the lower fuel costs it enjoys because of its ability to use less expensive high-sulfur fuel, allow it to make this payment. A mutually beneficial situation exists when the power plant pays a fee that permits a profitable operation for the chemical company, yet also allows savings for the power plant.

Although every effort was made to present realistic cost figures, there are many variations specific to each plant. Companies are encouraged to compare their situations with the base costs used in this presentation. Some reevaluation will no doubt be required to fit each specific location.

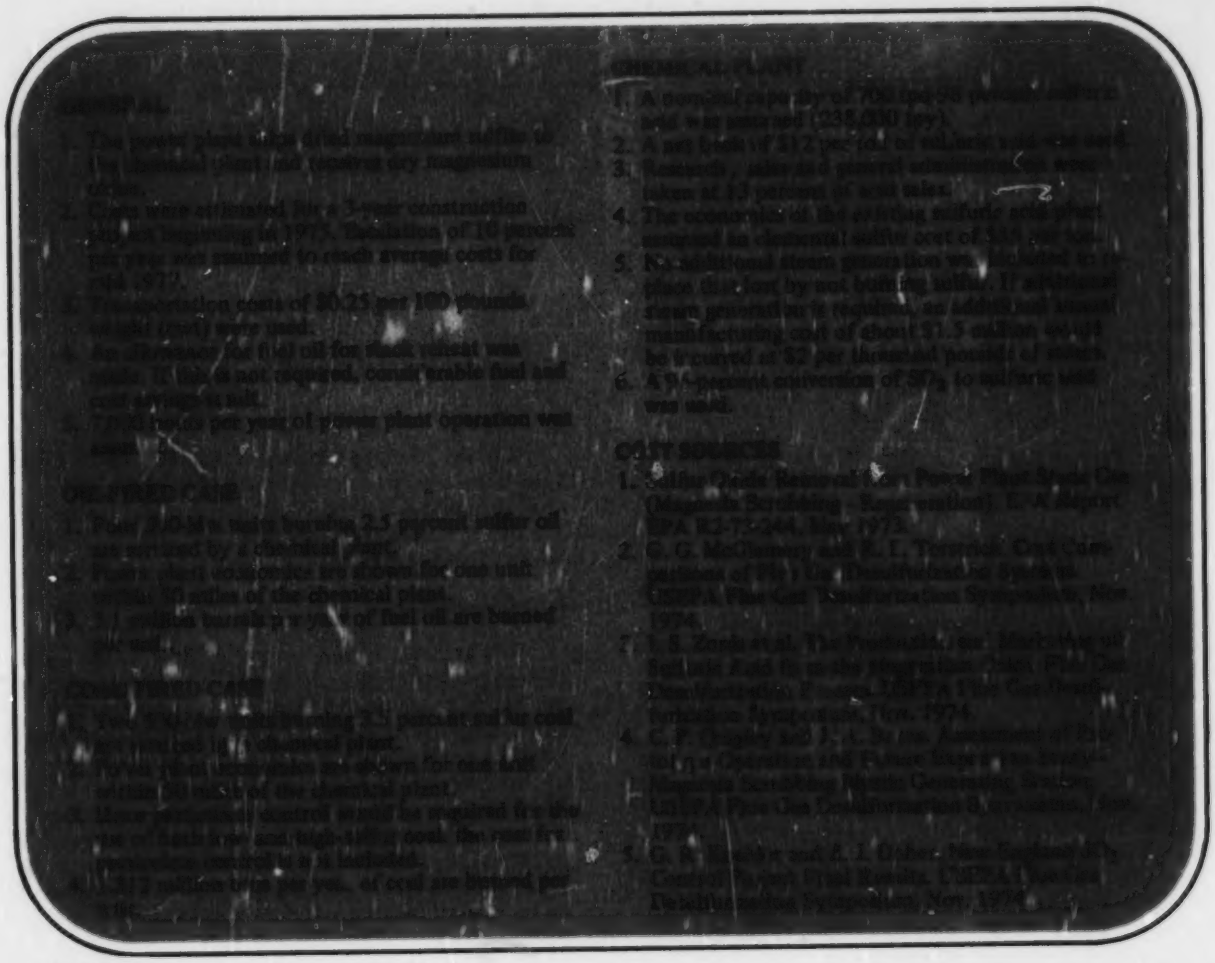


Table 3.
Basis for costs and economics

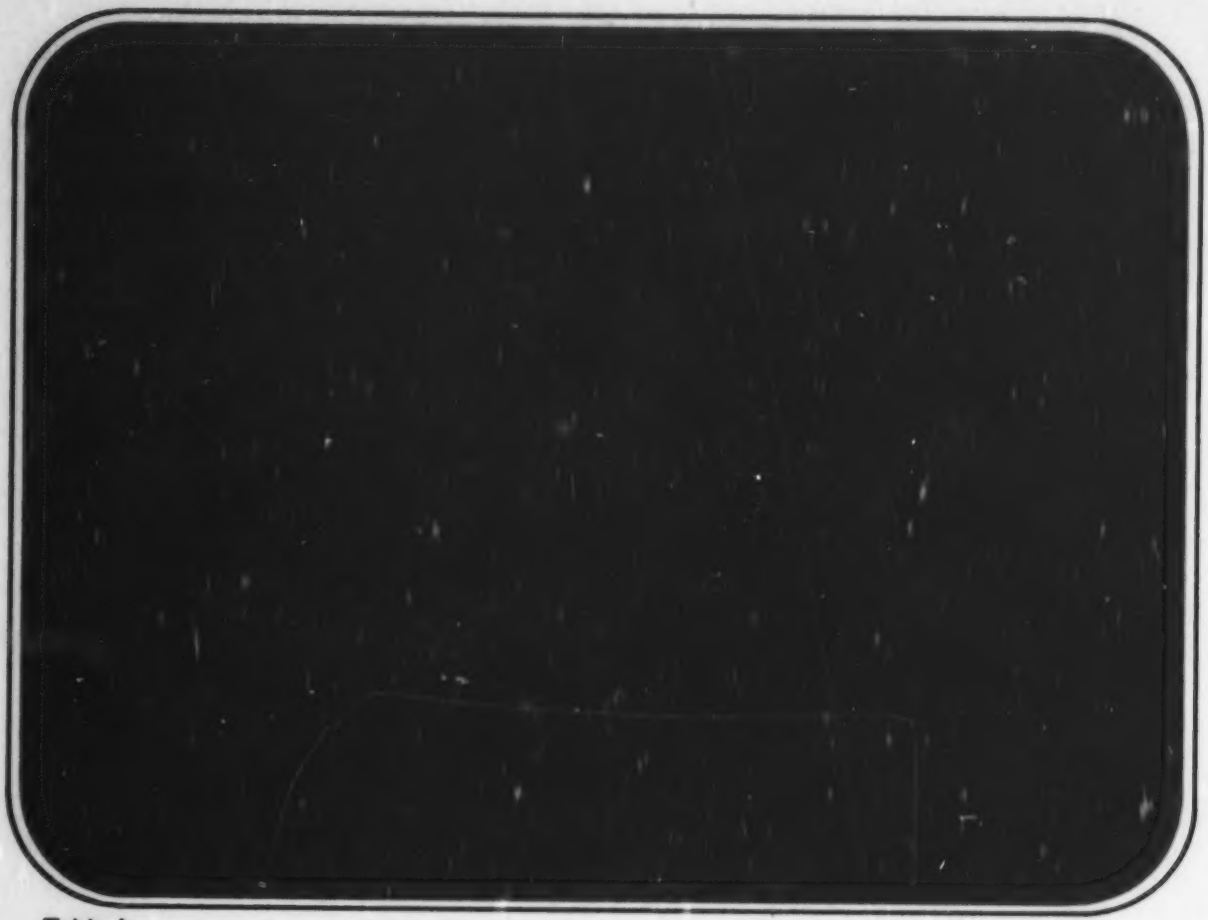


Table 4.
Annual cost for a 500-Mw oil-fired (2.5% S) unit shipping dried $MgSO_3$ to a chemical plant

The economics under the set of conditions defined in table 3 are examined for the case where the sulfur output from two 500-Mw units burning 3.5-percent sulfur coal are shipped to a sulfuric acid plant within 50 miles of the power plants. Reference materials used for this economic analysis are also shown in table 3.

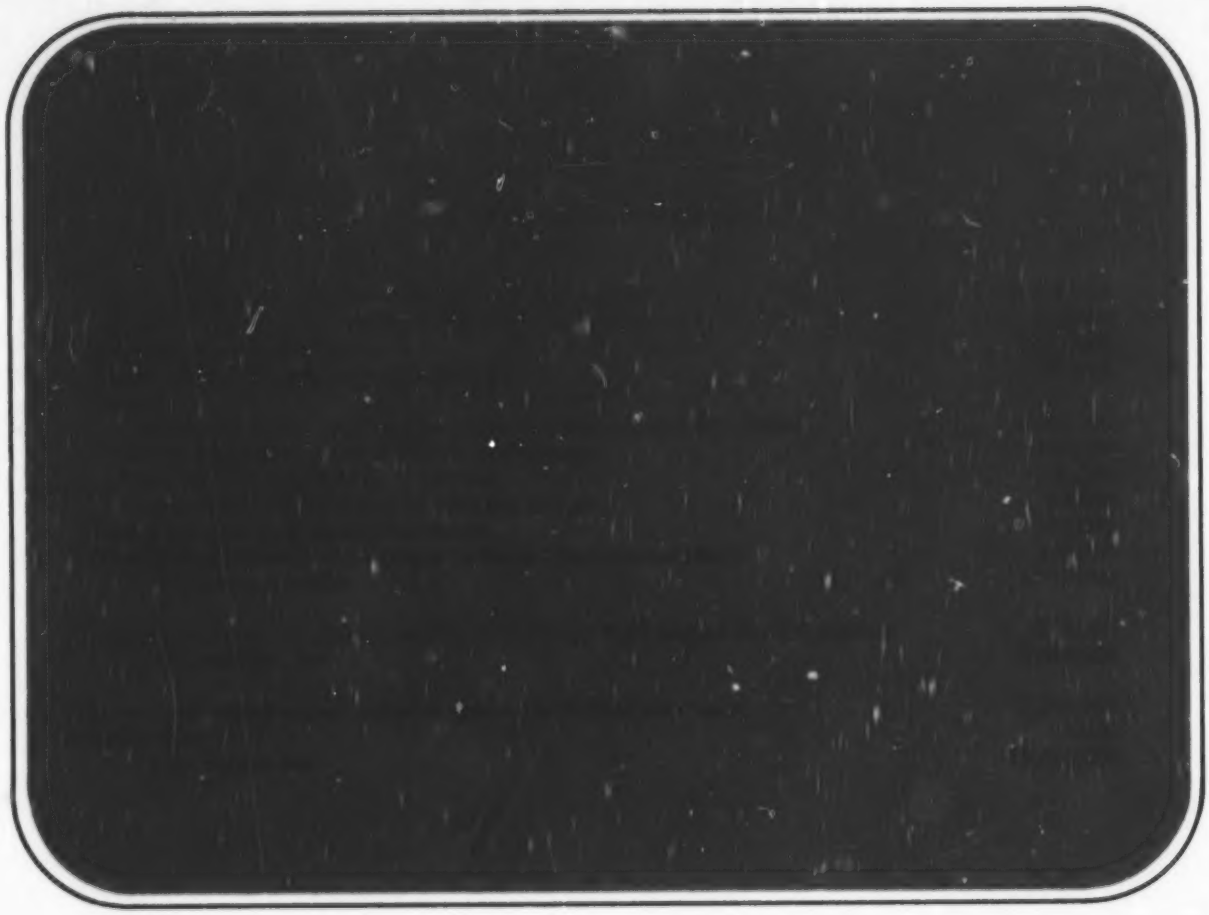


Table 5.
Annual cost for a 500-Mw coal-fired (3.5% S) unit shipping dried $MgSO_3$ to a chemical plant

A similar analysis is made for four 500-Mw plants burning 2.5 percent sulfur oil and feeding their magnesium sulfite output to a central sulfuric acid plant for regeneration. The costs for a completely new chemical plant and for an existing plant modified to accept magnesium sulfite are estimated. The investment and annualized costs for a single 500-Mw unit of the power plant in each case are given in tables 4 and 5. These costs were derived from the first four reference materials listed in table 3 and were checked for general conformance with engineered costs for a proposed installation.

Table 6.
Annual incremental manufacturing cost for an existing H_2SO_4 plant (calcination and SO_2 preparation facilities added)

The chemical plant would be of equal size in both instances. Manufacturing costs are given in table 6 for modifying an existing plant and table 7 for a new plant.

These economics are based upon definitive estimates for the case stated which are expected to be typical for many conditions. The costs for modification of the existing sulfuric acid plant are more difficult to evaluate, and will vary with the availability of physical space for retrofitting. The economics would be more favorable if the sulfuric acid plant were built adjacent to the power plant, since transportation costs are significant. The first reference material listed in table 3 is recommended for information on the sensitivity of the economics.

One option could be where a chemical plant takes the magnesium sulfite slurry, assumes responsibility for drying as well as calcining, and returns a magnesium oxide slurry. Although each situation may favor different arrangements, the economics given in this section outline general conditions for consideration of this technology.

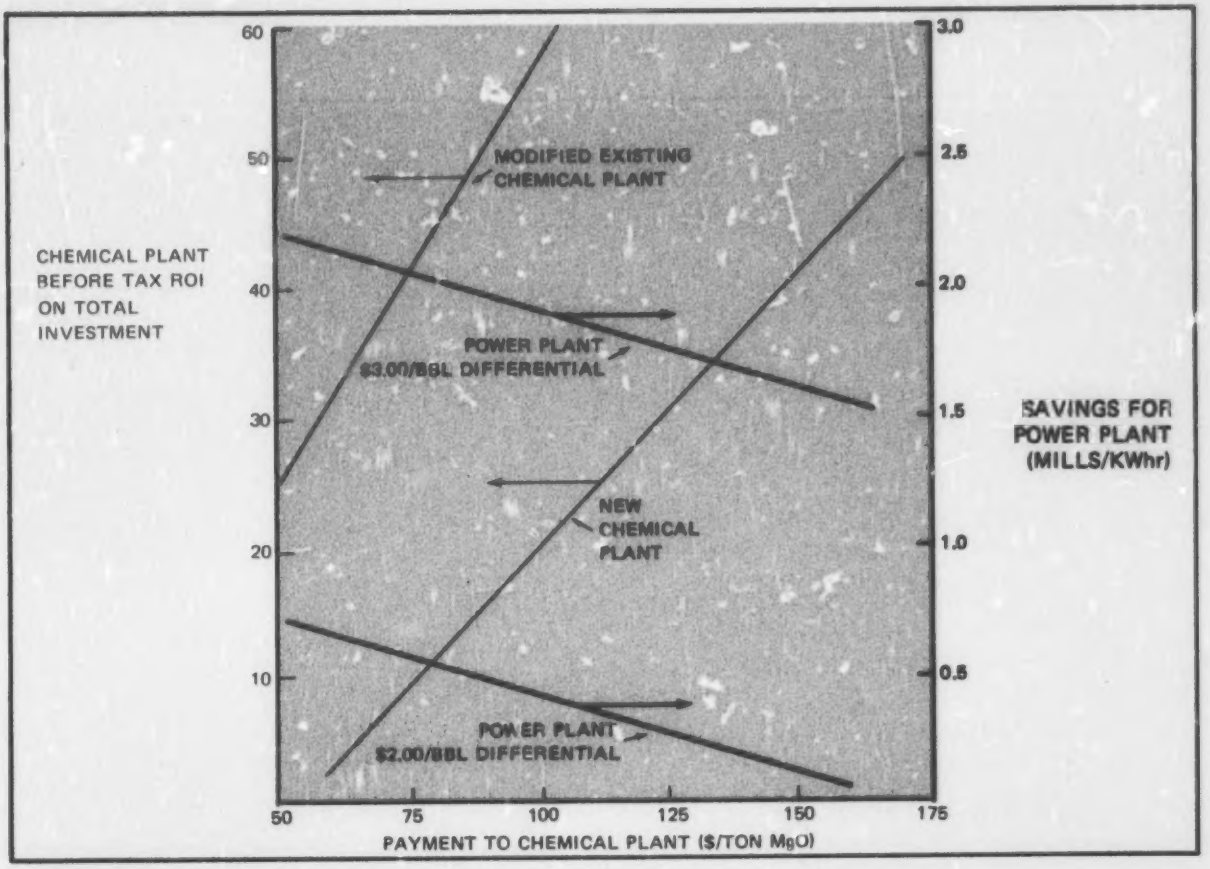
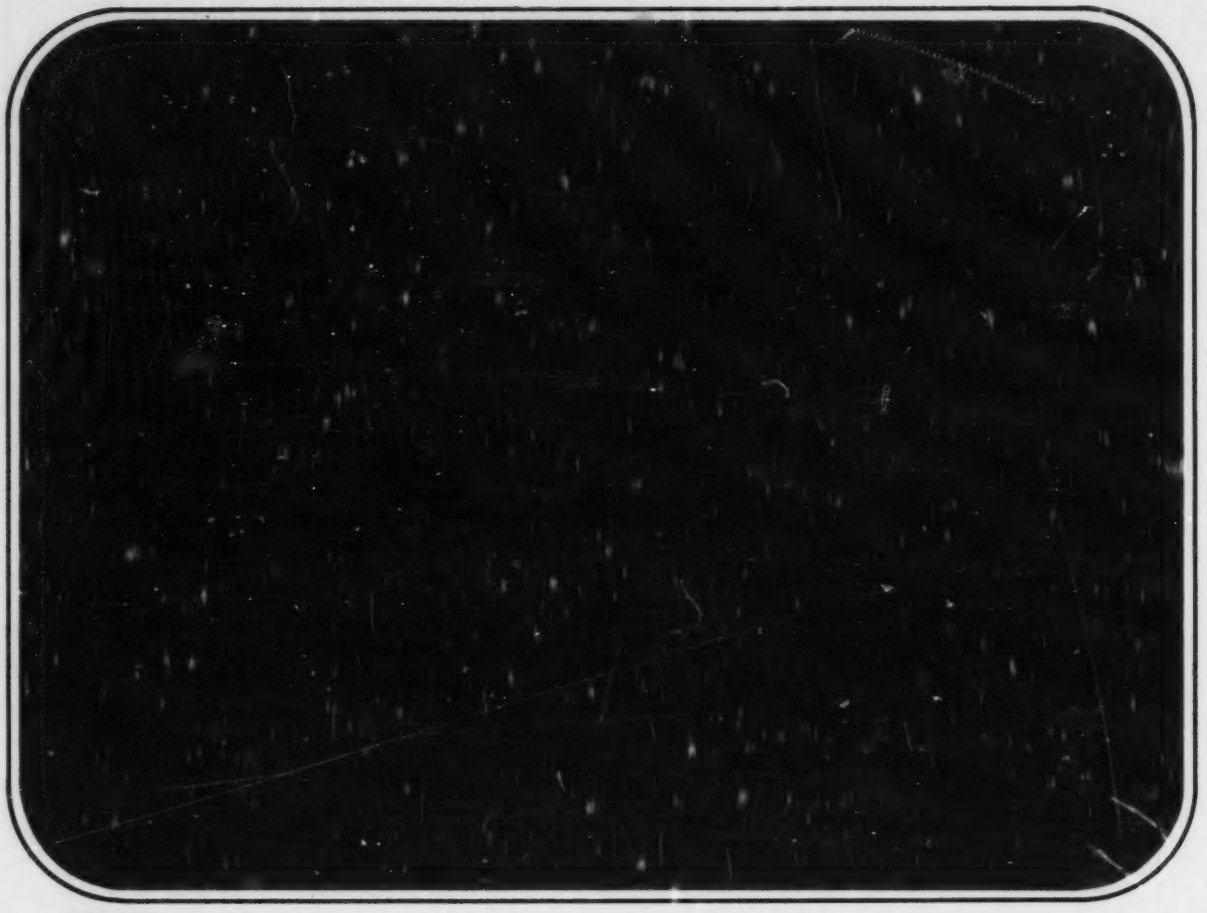


Figure 7.
Oil-fired power plant economics

Figure 7 summarizes the economics for the oil-fired situation under the base conditions. The savings in mills per kilowatt-hour (mills/kWhr), which the power plant would realize as a result of its ability to use high-sulfur oil, is plotted against the fee paid to the chemical company for several price differentials between high- and low-sulfur oil. The before-tax return on investment (ROI) for the chemical plant, as a function of this same fee, is also plotted for both the building of a new chemical plant and the modifying of an existing one.

Figure 7 points out areas of mutual benefit to both parties. Since the price differential for ½ percent and 2½ percent fuel oil is currently $3 per barrel (bbl), even at processing fees of $125 to $150 per ton of magnesium oxide (which would offer a 20- to 40-percent before-tax ROI to the chemical company building a new plant just to



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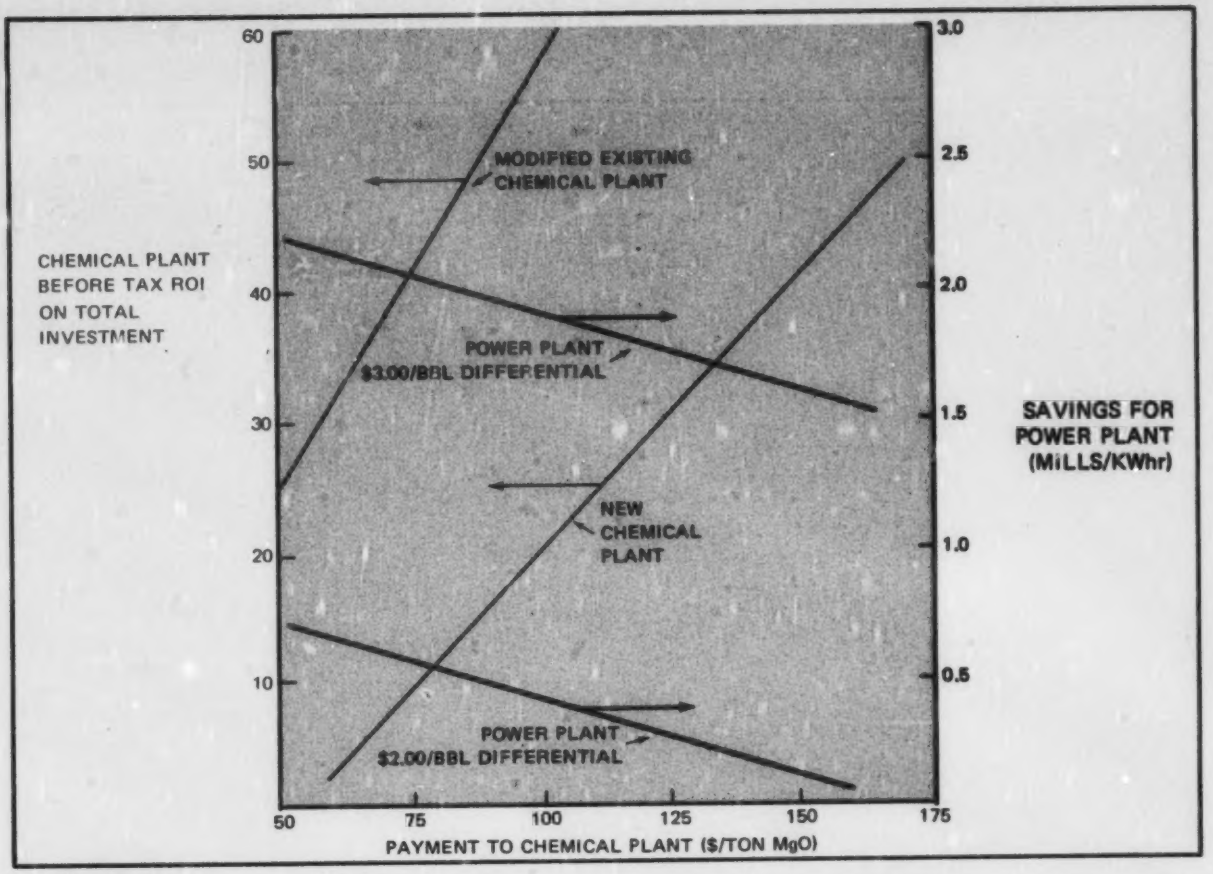

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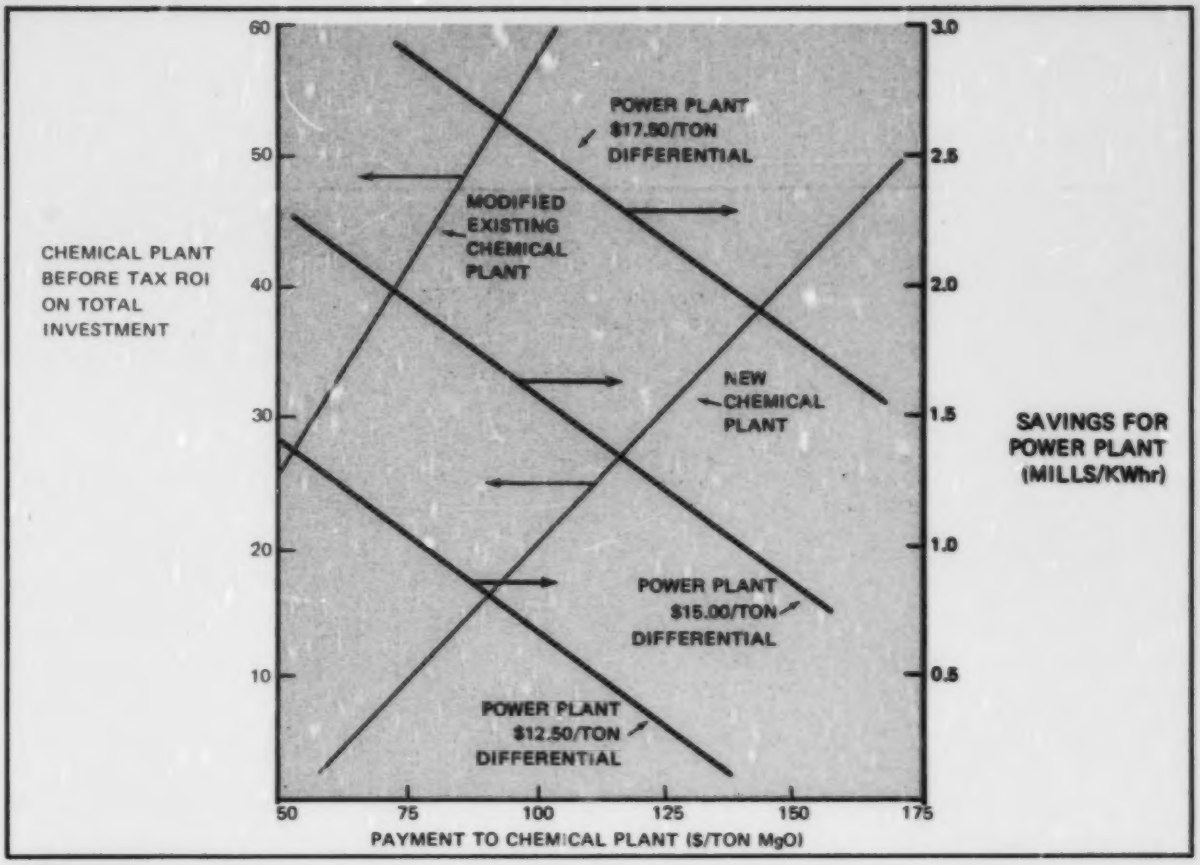

Figure 8.
Coal-fired power plant economics

process the magnesium sulfite), savings of 1.8 to 2.1 mills/kWhr would be realized.

The preliminary economics for an existing sulfuric acid plant, equipped with a calcination unit and modified to receive wet SO_2, appear even more favorable; this option offers savings of 2.1 to 2.4 mills/kWhr at the 20- to 40-percent before-tax ROI and fees of $50 to $75 per ton of magnesium oxide.

Figure 8 outlines the economics for the same sulfuric acid plant processing the magnesium sulfite from two 500-Mw coal-fired (3.5 percent) sulfur units. The areas of mutual interest under the assumed conditions are once again clearly shown for this case. Favorable economics are offered by a coal differential of $17.50 or $15 per ton. At $12.50 per ton, reasonable economics could be obtained only if an existing sulfuric acid plant were geographically situated in an optimal location.

Table 7.
Annual manufacturing cost for a new 700-TPD H_2SO_4 plant regenerating MgO

5. AREAS OF APPLICATION

This technology has special application in geographical areas near sulfuric acid markets and where land availability is limited for the disposal of sludges produced from throwaway flue gas desulfurization processes. It should also be of special interest to chemical or fertilizer companies that are paying premium prices for low-sulfur fuel for their power generation and have existing uses and markets for sulfuric acid.

Since the manufacture and sale of sulfuric acid is a specialized area outside the realm of power plant operations, an effective solution for both the chemical industry and the utility companies would appear to be the toll processing of the magnesium sulfite solids into reusable magnesium oxide and sulfuric acid by chemical companies. This could relieve the power plants of becoming involved in the manufacture and sale of sulfuric acid, and could minimize major market disruptions to chemical companies that could occur if power companies began to market large amounts of byproduct sulfuric acid.

The application of the calciner's high-SO_2 concentration offgas to other conventional sulfur-fixing production techniques, such as the production of elemental sulfur and liquid SO_2, is highly plausible. Such byproduct alternatives could alleviate problems associated with sulfuric acid market fluctuation or, for that matter, the nonavailability of a local sulfuric acid market.

Although the prototype plant was applied to an oil-fired boiler, the use of coal is not expected to affect the use of the technology as long as adequate provisions are made to remove fly ash from the flue gas prior to contact with the magnesia slurry. On this basis, and utilizing design and process experience gained, a Chemico-Basic magnesia scrubbing system has been installed at the Potomac Electric Power Company's coal-fired Dickerson Unit No. 3 boiler in Maryland, and is being operated in conjunction with regeneration and acid production at the Essex Chemical plant at Rumford, Rhode Island. Data obtained after 8 months of operation have not indicated any major differences from the operation at Boston Edison and Essex.

A United Engineers-designed magnesia slurry system has been applied to approximately 120 Mw at the Philadelphia Electric Company's coal-fired Eddystone No. 1 Unit, and is currently undergoing startup. The magnesium sulfite will be regenerated at the Olin Chemical sulfuric acid plant in Paulsboro, New Jersey.

For further information:

The detailed Project Report on this project is currently being prepared. If you wish to be notified when this final report is available, write:

Technology Transfer
Environmental Protection Agency
Washington, D.C. 20460